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(54) Title: α,β,β-TRIFLUOROSTYRENE-BASED AND SUBSTITUTED α,β,β-TRIFLUOROSTYRENE-BASED COMPOSITE MEMBRANES			
(57) Abstract			
<p>A composite membrane is provided in which a porous substrate is impregnated with a polymeric composition comprising various combinations of α,β,β-trifluorostyrene, substituted α,β,β-trifluorostyrene and ethylene-based monomeric units. Where the polymeric composition includes ion-exchange moieties, the resultant composite membranes are useful in electrochemical applications, particularly as membrane electrolytes in electrochemical fuel cells.</p>			

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**α,β,β -TRIFLUOROSTYRENE-BASED AND SUBSTITUTED
 α,β,β -TRIFLUOROSTYRENE-BASED COMPOSITE MEMBRANES**

Cross-Reference to Related Application

This application is a continuation-in-part of U.S. Patent Application Serial No. 08/442,206 filed May 16, 1995, which is a continuation of U.S. 5 Patent Application Serial No. 08/124,924 filed September 21, 1993, now U.S. Patent No. 5,422,411 issued June 6, 1995, entitled "Trifluorostyrene and Substituted Trifluorostyrene Copolymeric Compositions and Ion-exchange Membranes Formed Therefrom". The '206 and '924 applications, incorporated herein by reference in their entireties, describe polymeric compositions derived from copolymers of α,β,β -trifluorostyrene with a variety of substituted α,β,β -trifluorostyrenes. 10 These compositions are suitable for use as membranes, particularly as ion-exchange membranes. This application is also related to U.S. Patent Application Serial No. 08/480,098 filed June 6, 1995, entitled "Substituted Trifluorostyrene Compositions". The latter application, which is 15 also incorporated herein by reference in its entirety, describes copolymers of α,β,β -trifluorostyrene and substituted α,β,β -trifluorostyrenes, including sulfonyl fluoride substituted α,β,β -trifluorostyrene monomeric units that are 20 conveniently hydrolyzed to produce polymeric compositions with ion-exchange moieties. This application is further related to U.S. Patent Application Serial No. 08/482,948 filed June 7, 25 1995, entitled "Copolymeric Compositions of Trifluorostyrene, Substituted Trifluorostyrene and 30

- 2 -

Substituted Ethylene, and Ion-exchange Membranes Formed Therefrom". The latter application, which is also incorporated herein by reference in its entirety, describes copolymers of α,β,β -trifluorostyrene and substituted α,β,β -trifluorostyrenes with substituted ethylene monomeric units. These compositions are suitable for use as membranes, particularly as ion-exchange membranes.

Field Of The Invention

This invention relates generally to composite membranes comprising a porous substrate and a polymeric composition comprising various combinations of α,β,β -trifluorostyrene, substituted α,β,β -trifluorostyrene and ethylene-based monomeric units. Where the polymeric composition includes ion-exchange moieties, the resultant composite membranes are useful in electrochemical applications, particularly as membrane electrolytes in electrochemical fuel cells.

Background Of The Invention

Dense films can be obtained from solutions of poly- α,β,β -trifluorostyrene. However, the brittleness of these films greatly limits their application. Films obtained from some sulfonated poly- α,β,β -trifluorostyrenes can be used as ion-exchange membranes. However, such films often have unfavorable mechanical properties when wet, and are known to be very brittle in the dry state (see, for example, Russian Chemical Reviews, Vol. 59, p. 583 (1988)). Such films are of little practical use in fuel cells due to their poor physical properties. Some improvements in mechanical properties have

- 3 -

been achieved by blending sulfonated poly- α,β,β -trifluorostyrene with polyvinylidene fluoride and triethyl phosphate plasticizer, but these films remained unsatisfactory for application in
5 electrochemical cells (see Fuel Cell Handbook, A.J. Appleby, published by Van Nostrand Reinhold, p. 286 (1989)).

U.S. Patent No. 5,422,411 and the related patent applications mentioned above describe
10 various polymeric compositions incorporating substituted α,β,β -trifluorostyrenes and some cases further incorporating substituted ethylenes. Typically these compositions, as membranes, possess favorable mechanical properties compared to poly-
15 α,β,β -trifluorostyrene and sulfonated poly- α,β,β -trifluorostyrene, although some of the membranes have a tendency to become brittle in the fully dehydrated state, depending, for example, on the equivalent weight. This effect is most apparent at
20 equivalent weights below approximately 380 g/mol. Ion-exchange membranes derived from these polymeric compositions are suitable for many applications, including use in electrochemical applications, such as fuel cells.

25 For ease of handling, for example, in the preparation of membrane electrode assemblies for use in electrochemical fuel cells, the mechanical strength of the membrane in the dry state is important. In electrochemical applications, such as electrolytic cells and fuel cells, the dimensional stability (changes in the dimensions of the membrane due to changes in the degree of hydration) of the membrane during operation is also important. However, to improve performance, it is
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- 4 -

generally desirable to reduce membrane thickness and to decrease the equivalent weight (thereby increasing the water content) of the membrane electrolyte, both of which tend to decrease both
5 the mechanical strength in the dry state and the dimensional stability in the wet state. One way to improve mechanical strength and dimensional stability in ionomeric membranes is through use of a substrate or support material, to give a
10 composite membrane. The substrate is selected so that it imparts mechanical strength and dimensional stability to the membrane. The substrate material can be combined with the membrane polymeric material to form a composite membrane in a variety
15 of ways. For example, if possible, an unsupported membrane can be preformed and then laminated to the porous substrate. Alternatively, a solution of the polymer can be impregnated into the porous substrate material, and the composite membrane subsequently dried. The formation of composite
20 membranes via impregnation provides a more intimate contact between the two components, thus giving advantages over standard lamination approaches.

Composite ion-exchange membranes prepared by
25 impregnating commercially available porous polytetrafluoroethylene film (Gore-tex®) with Nafion®, a perfluorosulfonate ionomer, have been described in Journal of the Electrochemical Society, Vol. 132, pp. 514-515 (1985). The major
30 goal in the study was to develop a composite membrane with the desirable chemical and mechanical features of Nafion®, but which could be produced at low cost. Indeed, based on the polymer loadings necessary to produce these composite membranes,

- 5 -

they are a low cost alternative to the costly perfluorosulfonic acid membranes. As indicated above, however, these perfluorosulfonate ionomers are known to form membranes suitable for use in 5 electrochemical applications without the use of a substrate.

It has been discovered that polymers which have a tendency to become brittle in the dehydrated state can be rendered mechanically stable, even in 10 the fully dehydrated state, by impregnation into suitable substrates.

Furthermore, it has been discovered that even polymers which are poor film formers, or polymers which form films with mechanical properties and 15 dimensional stability which would preclude their use in electrochemical and other applications, can be made into composite membranes through incorporation into a suitable substrate. The resulting composite membranes have the desired 20 physical properties for use in a wide range of applications.

Summary Of The Invention

In one aspect of the present invention, a composite membrane comprises a porous substrate 25 impregnated with a polymeric composition comprising α,β,β -trifluorostyrene monomeric units.

In another aspect, a composite membrane comprises a porous substrate impregnated with a polymeric composition comprising substituted α,β,β -trifluorostyrene monomeric units. Substituted 30 α,β,β -trifluorostyrene monomeric units have at least one non-hydrogen substituent on the aromatic ring. In a preferred embodiment, the polymeric

- 6 -

composition comprises at least two different substituted α,β,β -trifluorostyrene monomeric units.

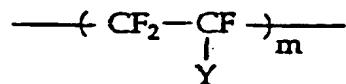
In a first embodiment of a composite membrane comprising a porous substrate impregnated with a 5 polymeric composition comprising α,β,β -trifluorostyrene monomeric units, the polymeric composition further comprises ethylene monomeric units, the polymeric composition derived from a copolymerization reaction involving at least 10 ethylene and α,β,β -trifluorostyrene.

In a second embodiment of a composite membrane comprising a porous substrate impregnated with a polymeric composition comprising α,β,β -trifluorostyrene monomeric units, the polymeric 15 composition further comprises partially fluorinated ethylene monomeric units, the polymeric composition derived from a copolymerization reaction involving at least α,β,β -trifluorostyrene and, for example, $\text{CH}_2=\text{CHF}$, $\text{CHF}=\text{CHF}$, $\text{CF}_2=\text{CH}_2$, or $\text{CF}_2=\text{CHF}$.

In a third embodiment of a composite membrane comprising a porous substrate impregnated with a polymeric composition comprising α,β,β -trifluorostyrene monomeric units, the polymeric composition further comprises tetrafluoroethylene 25 monomeric units, the polymeric composition derived from a copolymerization reaction involving at least tetrafluoroethylene and α,β,β -trifluorostyrene.

In a fourth embodiment of a composite membrane comprising a porous substrate impregnated with a 30 polymeric composition comprising α,β,β -trifluorostyrene monomeric units, the polymeric composition further comprises:

- 7 -



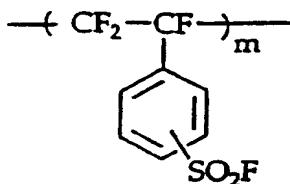
where m is an integer greater than zero; Y is selected from the group consisting of chlorine, bromine, iodine, $\text{C}_x\text{H}_y\text{F}_z$ (where x is an integer greater than zero and $y+z = 2x+1$), O-R (where R is selected from the group consisting of $\text{C}_x\text{H}_y\text{F}_z$ (where x is an integer greater than zero and $y+z = 2x+1$) and aryls), $\text{CF}=\text{CF}_2$, CN, COOH and $\text{CO}_2\text{R}'$ (where R' is selected from the group consisting of perfluoroalkyls, aryls, and $\text{NR}^2\text{R}'^3$ where R^2 and R'^3 are selected from the group consisting of hydrogen, alkyls and aryls).

In a fifth embodiment of a composite membrane comprising a porous substrate impregnated with a polymeric composition comprising α,β,β -trifluorostyrene monomeric units, the polymeric composition further comprises styrene monomeric units, the polymeric composition derived from a copolymerization reaction involving at least styrene and α,β,β -trifluorostyrene.

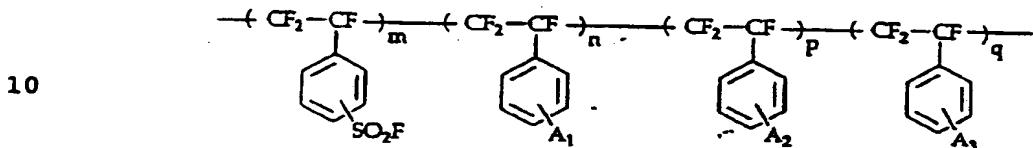
In a sixth embodiment of a composite membrane comprising a porous substrate impregnated with a polymeric composition comprising α,β,β -trifluorostyrene monomeric units, the polymeric composition further comprises substituted styrene monomeric units, the polymeric composition derived from a copolymerization reaction involving at least a substituted styrene and α,β,β -trifluorostyrene. Substituted styrene monomeric units have at least one non-hydrogen substituent on the aromatic ring.

- 8 -

In a first embodiment of a composite membrane comprising a porous substrate impregnated with a polymeric composition comprising substituted α, β, β -trifluorostyrene monomeric units, the polymeric composition comprises:



where m is an integer greater than zero. In a further embodiment the polymeric composition comprises:

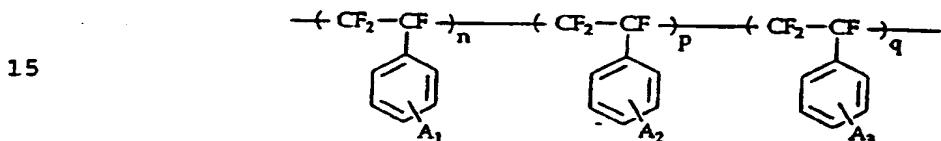


where m is an integer greater than zero, and at least one of n, p and q is an integer greater than zero; A₁, A₂ and A₃ are selected from the group consisting of hydrogen, halogens, C_xH_yF_z (where x is an integer greater than zero and y+z = 2x+1), CF=CF₂, CN, NO₂, and OH, O-R (where R is selected from the group consisting of alkyls and perfluoroalkyls and aryls). In a still further embodiment, the group from which A₁, A₂ and A₃ are selected further consists of SO₂H, PO₂H₂, PO₃H₂, CH₂PO₂H₂, COOH, OSO₃H, OPO₃H₂, OPO₂H₂, NR₂ (where R is selected from the group consisting of alkyls,

- 9 -

perfluoroalkyls and aryls) and CH_2NR_1^* (where R is selected from the group consisting of alkyls, perfluoroalkyls and aryls), and at least one of A_1 , A_2 and A_3 is selected from the group consisting of
5 SO_3H , PO_2H_2 , PO_3H_2 , $\text{CH}_2\text{PO}_3\text{H}_2$, COOH , OSO_3H , OPO_2H_2 , OPO_3H_2 , NR_1^* (where R is selected from the group consisting of alkyls, perfluoroalkyls and aryls) and CH_2NR_1^* (where R is selected from the group consisting of alkyls, perfluoroalkyls and aryls).

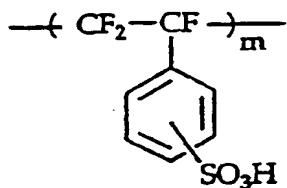
10 In a second embodiment of a composite membrane comprising a porous substrate impregnated with a polymeric composition comprising substituted α,β,β -trifluorostyrene monomeric units, the polymeric composition comprises:



where at least one of n, p and q is an integer greater than zero; A_1 , A_2 and A_3 , are selected from the group consisting of $\text{CF}=\text{CF}_2$, CN , NO_2 , and OH , $\text{O}-\text{R}$ (where R is selected from the group consisting of $\text{C}_x\text{H}_y\text{F}_z$ (where x is an integer greater than three and $y+z = 2x+1$), and aryls).

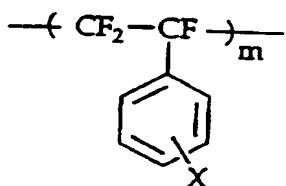
20 In a third embodiment of a composite membrane comprising a porous substrate impregnated with a polymeric composition comprising substituted α,β,β -trifluorostyrene monomeric units, the polymeric composition comprises:
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- 10 -



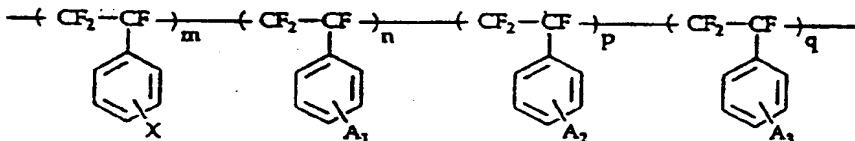
where m is an integer greater than zero.

In a fourth embodiment of a composite membrane comprising a porous substrate impregnated with a 5 polymeric composition comprising substituted α,β,β -trifluorostyrene monomeric units, the polymeric composition comprises:



10 where m is an integer greater than zero; X is selected from the group consisting of PO_2H_2 , PO_3H_2 , $\text{CH}_2\text{PO}_2\text{H}_2$, COOH , OSO_3H , OPO_2H_2 , OPO_3H_2 , OArSO_3H where Ar is an aryl, NR_3^+ (where R is selected from the group consisting of alkyls, perfluoroalkyls and aryls) and CH_2NR_3^+ (where R is selected from the group 15 consisting of alkyls, perfluoroalkyls and aryls).

15 In a fifth embodiment of a composite membrane comprising a porous substrate impregnated with a polymeric composition comprising substituted α,β,β -trifluorostyrene monomeric units, the polymeric 20 composition comprises:

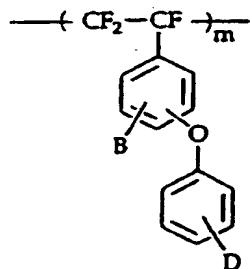


- 11 -

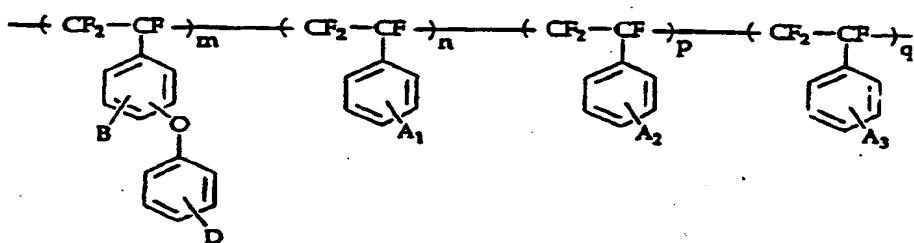
where m is an integer greater than zero, and at least one of n, p and q is an integer greater than zero; X is selected from the group consisting of SO₂H, PO₂H₂, PO₃H₂, CH₂PO₂H₂, COOH, OSO₂H, OPO₂H₂,
5 OPO₃H₂, OArSO₂H where Ar is an aryl, NR,^{*} (where R is selected from the group consisting of alkyls, perfluoroalkyls and aryls) and CH₂NR,^{*} (where R is selected from the group consisting of alkyls, perfluoroalkyls and aryls); A₁, A₂ and A₃ are
10 selected from the group consisting of halogens, C_xH_yF_z (where x is an integer greater than zero and y+z = 2x+1), CF=CF₂, CN, NO₂ and OH, O-R (where R is selected from the group consisting of alkyls and perfluoroalkyls and aryls). In a further
15 embodiment, the group from which A₁, A₂ and A₃ are selected further consists of hydrogen. In a still further embodiment, the group from which A₁, A₂ and A₃ are selected further consists of SO₂H, PO₂H₂,
PO₃H₂, CH₂PO₂H₂, COOH, OSO₂H, OPO₂H₂, OPO₃H₂, NR,^{*}
20 (where R is selected from the group consisting of alkyls, perfluoroalkyls and aryls) and CH₂NR,^{*} (where R is selected from the group consisting of alkyls, perfluoroalkyls and aryls), and at least one of A₁, A₂ and A₃ is selected from the group consisting of
25 SO₂H, PO₂H₂, PO₃H₂, CH₂PO₃H₂, COOH, OSO₂H, OPO₂H₂, OPO₃H₂, NR,^{*} (where R is selected from the group consisting of alkyls, perfluoroalkyls and aryls)
and CH₂NR,^{*} (where R is selected from the group consisting of alkyls, perfluoroalkyls and aryls).
30 In a sixth embodiment of a composite membrane comprising a porous substrate impregnated with a

- 12 -

polymeric composition comprising substituted α,β,β -trifluorostyrene monomeric units, the polymeric composition comprises:



- 5 where m is an integer greater than zero; B and D are selected from the group consisting of hydrogen, SO₂F, SO₂H, PO₂H₂, PO₂H, CH₂PO₂H₂, COOH, OSO₂H, OPO₂H₂, OPO₂H, NR,^{*} (where R is selected from the group consisting of alkyls, perfluoroalkyls and aryls) and CH₂NR,^{*} (where R is selected from the group consisting of alkyls, perfluoroalkyls and aryls).
10 In a further embodiment, the polymeric composition comprises:



- 15 where m is an integer greater than zero, and at least one of n, p and q is an integer greater than zero; B and D are selected from the group consisting of hydrogen, SO₂F, SO₂H, PO₂H₂, PO₂H, CH₂PO₂H₂, COOH, OSO₂H, OPO₂H₂, OPO₂H, NR,^{*} (where R is selected from the group consisting of alkyls, perfluoroalkyls and aryls) and CH₂NR,^{*} (where R is selected from the group consisting of alkyls,

- 13 -

perfluoroalkyls and aryls); A₁, A₂ and A₃ are selected from the group consisting of hydrogen, SO₂F, halogens, C_xH_yF_z (where x is an integer greater than zero and y+z = 2x+1), CF=CF₂, CN, NO₂ and OH,
5 O-R (where R is selected from the group consisting of alkyls and perfluoroalkyls and aryls). In a still further embodiment, the group from which A₁, A₂ and A₃ are selected further consists of SO₂H, PO₂H₂, PO₂H, CH₂PO₂H₂, COOH, OSO₂H, OPO₂H₂, OPO₂H, NR,
10 (where R is selected from the group consisting of alkyls, perfluoroalkyls and aryls) and CH₂NR, (where R is selected from the group consisting of alkyls, perfluoroalkyls and aryls), and at least one of A₁, A₂ and A₃ is selected from the group consisting of SO₂H, PO₂H₂, PO₂H, CH₂PO₂H₂, COOH, OSO₂H, OPO₂H₂,
15 OPO₂H₂, NR, (where R is selected from the group consisting of alkyls, perfluoroalkyls and aryls) and CH₂NR, (where R is selected from the group consisting of alkyls, perfluoroalkyls and aryls).
20 In preferred embodiments B is hydrogen.

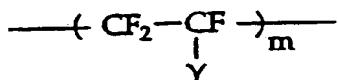
In a seventh embodiment of a composite membrane comprising a porous substrate impregnated with a polymeric composition comprising substituted α,β,β-trifluorostyrene monomeric units, the
25 polymeric composition further comprises ethylene monomeric units.

In an eighth embodiment of a composite membrane comprising a porous substrate impregnated with a polymeric composition comprising substituted α,β,β-trifluorostyrene monomeric units, the
30 polymeric composition further comprises partially fluorinated ethylene monomeric units, the polymeric composition derived from a copolymerization reaction involving, for example, CH₂=CHF, CHF=CHF.

- 14 -

In a ninth embodiment of a composite membrane comprising a porous substrate impregnated with a polymeric composition comprising substituted α,β,β -trifluorostyrene monomeric units, the polymeric
5 composition further comprises tetrafluoroethylene monomeric units.

In a tenth embodiment of a composite membrane comprising a porous substrate impregnated with a polymeric composition comprising substituted α,β,β -trifluorostyrene monomeric units, the polymeric
10 composition further comprises:



where m is an integer greater than zero; Y is selected from the group consisting of chlorine, bromine, iodine, $\text{C}_x\text{H}_y\text{F}_z$ (where x is an integer greater than zero and $y+z = 2x+1$), O-R (where R is selected from the group consisting of $\text{C}_x\text{H}_y\text{F}_z$ (where x is an integer greater than zero and $y+z = 2x+1$) and aryls), $\text{CF}=\text{CF}_2$, CN, COOH and $\text{CO}_2\text{R}'$ (where R' is selected from the group consisting of alkyls, perfluoroalkyls, aryls, and $\text{NR}^2\text{R}'^3$ where R^2 and R'^3 are selected from the group consisting of hydrogen, alkyls and aryls).
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In an eleventh embodiment of a composite membrane comprising a porous substrate impregnated with a polymeric composition comprising substituted α,β,β -trifluorostyrene monomeric units, the polymeric composition further comprises styrene
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- 15 -

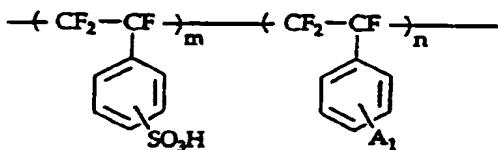
monomeric units.

In a twelfth embodiment of a composite membrane comprising a porous substrate impregnated with a polymeric composition comprising substituted α, β, β -trifluorostyrene monomeric units, the polymeric composition further comprises substituted styrene monomeric units. Substituted styrene monomeric units have at least one non-hydrogen substituent on the aromatic ring.

10 In the aspects and embodiments described above, the substrate is preferably a porous film or sheet material. For electrochemical applications, for example, preferred porous substrates comprise, or consist essentially of, porous polyolefins.

15 Preferred polyolefins are polyethylene and polypropylene. Particularly preferred substrates comprise, or consist essentially of, porous polytetrafluoroethylene, also known as expanded polytetrafluoroethylene.

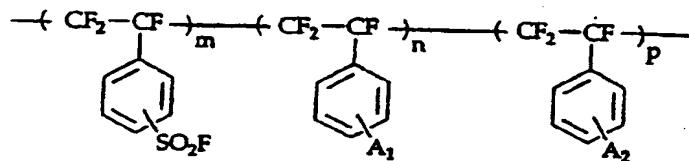
20 In a preferred aspect, a composite membrane comprises a porous substrate impregnated with a polymeric composition comprising:



25 where m and n are integers greater than zero and A₁ is selected from the group consisting of fluorine, CF, and para-phenoxy. In a further embodiment of this preferred aspect, the group from which A₁ is selected further consists of hydrogen.

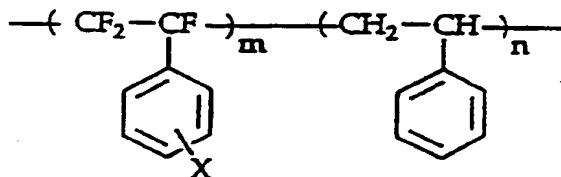
- 16 -

In another preferred aspect, a composite membrane comprises a porous substrate impregnated with a polymeric composition comprising:



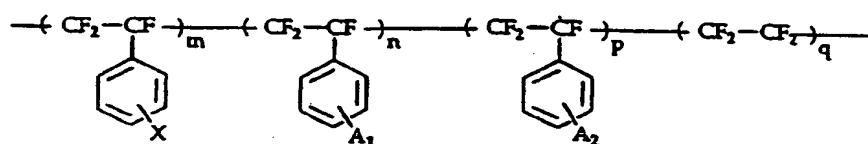
5 where m, n, and p are integers greater than zero and A₁ and A₂ are selected from the group consisting of hydrogen, fluorine, CF₃, and para-phenoxy.

10 In another preferred aspect, a composite membrane comprises a porous substrate impregnated with a polymeric composition comprising:



where m and n are integers greater than zero and X is selected from the group consisting of para-SO₂F, meta-SO₂H and para-SO₃H.

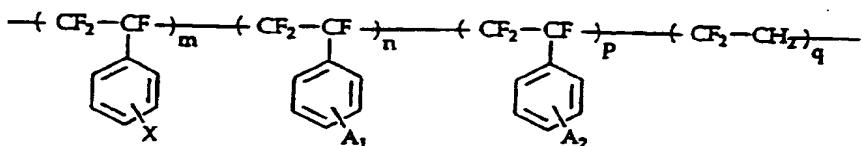
15 In yet another preferred aspect, a composite membrane comprises a porous substrate impregnated with a polymeric composition comprising:



- 17 -

where m and q are integers greater than zero, n and p are zero or an integer greater than zero; X is selected from the group consisting of para-SO₂F, meta-SO₂H and para-SO₂H; and A₁ and A₂ are selected from the group consisting of hydrogen, fluorine, CF₃, and para-phenoxy. In a further embodiment of this preferred aspect, n is an integer greater than zero.

In still another preferred aspect, a composite membrane comprises a porous substrate impregnated with a polymeric composition comprising:



where m and q are integers greater than zero, n and p are zero or an integer greater than zero; X is selected from the group consisting of para-SO₂F, meta-SO₂H and para-SO₂H; and A₁ and A₂ are selected from the group consisting of hydrogen, fluorine, CF₃, and para-phenoxy. In a further embodiment of this preferred aspect, n is an integer greater than zero.

In the aspects and embodiments described above, the polymeric compositions can consist essentially of the described monomeric units.

In all of the above preferred aspects, preferably the porous substrate comprises polytetrafluoroethylene. A preferred porous substrate consists essentially of

polytetrafluoroethylene.

In the aspects and embodiments described above, the A₁, A₂, A, substituents may be further elaborated by known means such as, for example, by hydrolysis of the CN group to form COOH or by reduction with common reducing agents (such as, for example, Raney nickel) to form a primary amine, thereby transforming the A₁, A₂ and A, substituents into ion-exchange moieties. The resulting polymeric composition may thus comprise one or more type of ion-exchange moiety, and may also comprise both cation and anion exchange moieties.

The term "monomeric unit" as used herein indicates that the polymeric composition contains the described fragment or unit, and is obtained by a polymerization reaction involving the corresponding unsaturated monomer.

The substituents on the aromatic rings (including, for example, A₁, A₂, A, X, B and D) may each be located in the ortho, meta or para positions, as indicated in the formulas wherein the chemical bond drawn for the substituents intersects the aromatic ring. In preferred aspects of the described embodiments, the substituents are in the meta or para positions.

As used herein, the term "aryl" refers to a substituted or unsubstituted phenyl group. The formula C_xH_yF_z (where x is an integer greater than zero and y+z = 2x+1) is used to indicate alkyl, perfluoroalkyl or partially fluorinated alkyl groups.

In accordance with convention in the art, the above chemical formulas for polymeric compositions containing more than two monomeric units (where at

- 19 -

least three of m, n, p and q are greater than zero) are intended to indicate that the monomeric units are present in the polymeric composition, but are not limited to the particular order in which the 5 monomeric units are set forth in each general formula. For example, random linear copolymers, alternating copolymers and linear block copolymers, formed from the indicated monomeric units, are contemplated.

10 Brief Description Of The Drawings

FIG. 1 is a plot of cell voltage as a function of current density (expressed in amperes per square foot or "ASF") in an electrochemical fuel cell employing a composite membrane of porous polyethylene impregnated with a sulfonated copolymer of α,β,β -trifluorostyrene and m-trifluoromethyl- α,β,β -trifluorostyrene, as the proton exchange membrane.

20 FIG. 2 is a plot of cell voltage as a function of current density in an electrochemical fuel cell employing a composite membrane, prepared by impregnation of porous polyethylene with sulfonated poly- α,β,β -trifluorostyrene, as the proton exchange membrane.

25 FIG. 3 is a plot of cell voltage as a function of current density in an electrochemical fuel cell employing a composite membrane, prepared by impregnation of porous polyethylene with a copolymer of α,β,β -trifluorostyrene, 30 m-trifluoromethyl- α,β,β -trifluorostyrene and p-sulfonyl fluoride- α,β,β -trifluorostyrene, and subsequent hydrolysis, as the proton exchange membrane.

- 20 -

FIG. 4 is a plot of cell voltage as a function of current density in an electrochemical fuel cell employing a composite membrane of expanded polytetrafluoroethylene impregnated with a sulfonated copolymer of α,β,β -trifluorostyrene and m -trifluoromethyl- α,β,β -trifluorostyrene, as the proton exchange membrane.

FIG. 5 is a plot of cell voltage as a function of current density in an electrochemical fuel cell employing a composite membrane of expanded polytetrafluoroethylene impregnated with a low equivalent weight sulfonated copolymer of α,β,β -trifluorostyrene and m -trifluoromethyl- α,β,β -trifluorostyrene, as the proton exchange membrane.

15 Detailed Description Of The Preferred Embodiments

Methods for preparing the polymeric compositions described herein are described in the related applications or will be apparent to those skilled in the art.

20 The preferred substrate material is dependent on the application in which the composite membrane is to be used. The substrate material preferably has good mechanical properties, is chemically and thermally stable in the environment in which the composite membrane is to be used, is tolerant of the solvent used for impregnation, and in most applications is preferably flexible. For example, the porous substrate can be a woven or nonwoven fabric or cloth, or can be made of paper, fiber glass, cellulosics or a ceramic material.

25 Preferred substrates for electrochemical applications are porous polymeric materials. Preferred polymeric materials are, for example,

- 21 -

hydrocarbons such as porous polyolefins, especially polyethylene and polypropylene. In some applications, a perfluorinated polymeric substrate may be preferred, for example, a preferred 5 substrate material, when the composite membrane is to be used in an electrochemical fuel cell, is porous polytetrafluoroethylene, also known as expanded polytetrafluoroethylene. Porous polyolefins and polytetrafluoroethylenes typically 10 have excellent mechanical strength, flexibility and do not swell in water. Polytetrafluoroethylene offers additional advantages in that it is also chemically inert, and porous polytetrafluoroethylene films with different 15 characteristics are commercially available from various sources. It may be possible to obtain or prepare other suitable porous polymeric substrates from, such as, for example, polyvinylidene fluoride or polysulfones. Copolymeric substrates such as, 20 for example, poly(ethylene-co-tetrafluoroethylene) and poly(tetrafluoroethylene-co-hexafluoropropylene), may also be used.

The degree of porosity, pore size and thickness of the substrate used in the composite 25 membrane can be selected to suit the application. For use of the composite membrane as an electrolyte in an electrochemical fuel cell, the substrate thickness is preferably 10-200 µm, and more preferably 25-50 µm, the preferable average pore 30 diameter is 0.1-1.0 µm, and the preferable porosity is 50-98%, more preferably 75-90%.

Depending on the application the resultant composite membrane may be gas permeable or gas impermeable. The loading of the polymeric

- 22 -

composition on the substrate can be varied in order to control the porosity of the resultant composite membrane. For fuel cell applications, the composite membrane is preferably substantially gas impermeable, thus the degree of impregnation and loading is such that the porosity of the composite membrane is reduced essentially to zero.

In a method for preparing composite membranes, the polymeric composition is dissolved in a solvent, typically an organic solvent, to form a solution. The solvent used will depend, for example, on both the nature of the polymeric composition and the substrate. For impregnation of porous polyolefins with the type of polymeric compositions described herein, suitable solvents include N,N-dimethylformamide, N-methylpyrrolidone, dimethylsulfoxide and N,N-dimethylacetamide. When polytetrafluoroethylene is the substrate, an alcohol or mixture of alcohols (chosen, for example, from methanol, ethanol and propan-2-ol) is often the preferred solvent. The concentration of the solution will depend on the loading desired, and whether the composite membrane is to be porous or not. For example, if the composite membrane is to be gas permeable a lower concentration is generally preferred.

The porous substrate is then impregnated, for example, by constraining the substrate in a frame and dipping or soaking it in the solution. The contact time is dependent on the viscosity and percentage solids of the solution. Other techniques known in the art, such as ultrasonication, may be used to facilitate impregnation. Also, multiple impregnations,

- 23 -

possibly with different polymeric compositions, may be desirable for some applications. The substrate is then removed from the solution and the composite membrane dried preferably in a humidity controlled 5 atmosphere (generally at less than or equal to 2% relative humidity) at above ambient temperatures.

If the composite membrane includes proton-exchange moieties and is to be used in, for example, a proton-exchange membrane fuel cell, it 10 is removed from the frame, treated with 1 M hydrochloric acid and washed with deionized water prior to use.

The means by which the process described above could be modified for impregnation of non-membrane 15 substrates, and also for a continuous composite membrane manufacturing process will be apparent to those skilled in the art.

In the preparation of composite ion-exchange membranes, the ion-exchange moieties can be:

20 (i) present in the polymeric composition prior to its impregnation into the substrate; or

(ii) introduced post-impregnation through further reaction of the polymeric composition on the substrate; or

25 (iii) introduced via conversion of precursor groups, present in the polymeric composition, after impregnation.

If the ion-exchange moieties are to be introduced via a post-impregnation conversion or 30 reaction, the substrate needs to be selected such that it can withstand the post-impregnation treatment step. For example, in post-impregnation introduction of ion-exchange moieties, the ion-exchange moieties may be introduced into polymeric

- 24 -

compositions containing unsubstituted α,β,β -trifluorostyrene units (so called "base polymers") via aromatic substitution of at least a portion of those units, after preparation of a composite membrane. For example, pendant unsubstituted phenyl rings in the composite membrane can be conveniently sulfonated (see U.S. Patent 5,422,411) to produce a composite cation-exchange membrane. Similarly, such pendant unsubstituted phenyl rings may be phosphorylated, carboxylated, quaternary-aminoalkylated or chloromethylated, and further modified to include $-\text{CH}_2\text{PO}_2\text{H}_2$, $-\text{CH}_2\text{NR}$, where R is an alkyl, or $-\text{CH}_2\text{NAr}$, (where Ar is a substituted or unsubstituted phenyl group) and other substituents, to provide cation-exchange or anion-exchange composite membranes. Further still, the pendant phenyl moiety may contain a hydroxyl group which can be elaborated by known methods to generate $-\text{OSO}_3\text{H}$, $-\text{OPO}_2\text{H}_2$, and $-\text{OPO}_3\text{H}_2$ cation-exchange sites on the composite membrane.

The approach in which the ion-exchange functionality is introduced post-impregnation via conversion of a precursor using simple post-impregnation procedure, such as hydrolysis, can be advantageous. For example, composite membranes comprising polymers containing sulfonyl fluoride moieties ($-\text{SO}_2\text{F}$) can be hydrolyzed to generate $-\text{SO}_3\text{H}$ cation-exchange sites. In a typical hydrolysis reaction, the sulfonyl fluoride is converted to the free sulfonic acid functionality by treatment of the composite membrane with concentrated aqueous alkali metal hydroxide at elevated temperatures. This and other procedures for the hydrolysis of $-\text{SO}_2\text{F}$ to $-\text{SO}_3\text{H}$ are well-known to those skilled in the

- 25 -

art. The latter approach to the introduction of -SO₃H moieties offers advantages over sulfonation of a base polymer in the composite membrane. For example, it permits greater control over the ion-exchange capacity of the resultant composite membrane.

Membranes including sulfonyl fluoride substituted α,β,β-trifluorostyrene monomeric units are described in a related application.

10 Unsupported membranes containing a significant proportion of sulfonyl fluoride substituted α,β,β-trifluorostyrene monomeric units can be very fragile. The mechanical properties of these precursor ion-exchange membranes can be

15 significantly enhanced through incorporation into a porous substrate.

It may be advantageous to introduce ion-exchange moieties after preparation of the composite membranes, as described in (ii) and (iii) above. For example, in electrochemical applications where the preferred substrates are typically hydrophobic, the preparation of a composite membrane by first impregnating the substrate with a solution of a non-ionic polymer

20 which is also essentially hydrophobic may lead to more facile and improved impregnation.

The following examples are for purposes of illustration and are not intended to limit the invention. Examples 1-3 describe the preparation of composite ion-exchange membranes in which porous, high density polyethylene is used as the substrate. Examples 4 and 5 describe the preparation of composite ion-exchange membranes in which expanded polytetrafluoroethylene is used as

- 26 -

the porous substrate. In Examples 1, 2, 4 and 5 the ion-exchange moieties were present in the polymeric composition prior to its impregnation into the substrate. In Example 3 the ion-exchange moiety was generated by hydrolysis of sulfonyl fluoride moieties after preparation of the composite membrane. Example 6 sets forth the procedure used to test the composite ion-exchange membranes, prepared as described in Examples 1-5, 10 as membrane electrolytes in an electrochemical fuel cell.

Example 1

Porous polyethylene impregnated with a sulfonated copolymer of α,β,β -trifluorostyrene and m-trifluoromethyl- α,β,β -trifluorostyrene
(Composite Membrane A)

The substrate, a 9 inch x 9 inch piece of high density polyethylene (obtained from 3M, product ID #43-9100-6770-1, 81% porosity, approximately 50 micron) was clamped in a frame and immersed in a N,N-dimethylformamide solution (7% w/w) of a sulfonated copolymer of α,β,β -trifluorostyrene and m-trifluoromethyl- α,β,β -trifluorostyrene (equivalent weight 384 g/mol) in a glass container. The container was covered to exclude moisture and particulate contaminants. After 1 hour excess polymer solution was removed and the transparent, wetted substrate was placed to dry in a chamber at approximately 2% relative humidity, at 50°C. After approximately 3 hours the dry composite membrane, now opaque, was a mechanically strong flexible film. On immersion in 1 M hydrochloric acid (to

- 27 -

ensure protonation of all the sulfonic acid moieties), and subsequent washing with deionized water, the composite membrane once again became transparent. The wet composite membrane (50-60 5 micron thick) was also strong and flexible.

Example 2

Porous polyethylene impregnated with
sulfonated poly- α,β,β -trifluorostyrene
(Composite Membrane B)

10 The substrate, a 10 inch x 10 inch piece of high density polyethylene (from 3M, product ID #43-9100-6770-1, 81% porosity, 50 micron) was clamped in a frame and immersed in a N,N-dimethylformamide solution (7% w/w) of a sulfonated polymer of α,β,β -trifluorostyrene (equivalent weight 430 g/mol) in a glass container. The container was covered to exclude moisture and particulate contaminants. After 2 hours excess polymer solution was removed and the transparent, wetted substrate was placed to 15 dry in a chamber at approximately 2% relative humidity, at 50°C. After approximately 3 hours the dry composite membrane, now opaque, was a mechanically strong flexible film, in contrast to the analogous unsupported membrane which would be extremely fragile in the dry state. On immersion 20 in 1 M hydrochloric acid (to ensure protonation of all the sulfonic acid moieties), and subsequent washing with deionized water, the composite membrane once again became transparent. The wet composite membrane (approximately 100 micron thick) 25 was also strong and flexible.

- 28 -

Example 3

Porous polyethylene impregnated with a copolymer of
α,β,β-trifluorostyrene,
m-trifluoromethyl-α,β,β-trifluorostyrene and
5 p-sulfonyl fluoride-α,β,β-trifluorostyrene, and
subsequent hydrolysis
(Composite Membrane C)

The substrate, a 10 inch x 10 inch piece of
high density polyethylene (from 3M, product ID #43-
10 9100-6770-1, 81% porosity, approximately 50 micron)
was clamped in a frame and immersed in a N,N-
dimethylformamide solution (5% w/w) of a copolymer
of α,β,β-trifluorostyrene, m-trifluoromethyl-α,β,β-
15 trifluorostyrene and p-sulfonyl fluoride-α,β,β-tri-
fluorostyrene (equivalent weight 480 g/mol after
hydrolysis) in a glass container. The container
was covered to exclude moisture and particulate
contaminants. After 2 hours excess polymer
solution was removed and the transparent, wetted
20 substrate was placed to dry in a chamber at
approximately 2% relative humidity, at 50°C. After
approximately 3 hours the dry composite membrane
was a mechanically strong flexible film. The
sulfonyl fluoride moieties were hydrolyzed by
25 treatment of the composite membrane with potassium
hydroxide solution (approximately 6% w/w, in 5:1
w/w water:1-methoxy-2-propanol) at 60°C (see U.S.
Patent No. 5,310,765). The composite membrane was
then immersed in 1 M hydrochloric acid to ensure
30 protonation of all the sulfonic acid moieties in
the composite membrane, and subsequently washed
with deionized water. The wet, hydrolyzed
composite membrane (50-70 micron thick) was also

- 29 -

strong and flexible.

Example 4

Expanded polytetrafluoroethylene impregnated with a sulfonated copolymer of α,β,β -trifluorostyrene and
5 m -trifluoromethyl- α,β,β -trifluorostyrene
(Composite Membrane D)

The substrate, an 8 inch x 8 inch piece of expanded polytetrafluoroethylene (Tetratex® obtained from Tetratec Corporation, 80-90% porosity, approximately 38 micron, 0.45 micron pore size) was clamped in a frame and immersed in a methanol/propan-2-ol (3:1) solution (approximately 5% w/v) of a sulfonated copolymer of α,β,β -tri-fluorostyrene and m -trifluoromethyl- α,β,β -tri-fluorostyrene (equivalent weight 412 g/mol) in a glass container. The container was covered to exclude moisture and particulate contaminants. After 18 hours excess polymer solution was removed and the transparent, wetted substrate was placed to dry in a chamber at approximately 2% relative humidity, at 50°C. After approximately 1.5 hours the dry composite membrane, now opaque, was a mechanically strong flexible film. On immersion in 1 M hydrochloric acid (to ensure protonation of all the sulfonic acid moieties), and subsequent washing with deionized water, the composite membrane once again became transparent. The wet composite membrane (50-60 micron thick) was also strong and flexible.

- 30 -

Example 5

Expanded polytetrafluoroethylene impregnated with a sulfonated copolymer of α,β,β -trifluorostyrene and m -trifluoromethyl- α,β,β -trifluorostyrene

5 (Composite Membrane E)

The composite membrane was prepared as described in Example 4, using a sulfonated copolymer of α,β,β -trifluorostyrene and m -trifluoromethyl- α,β,β -trifluorostyrene with a lower equivalent weight (362 g/mol) and impregnating the substrate for 30 minutes. The resulting dry composite membrane was a mechanically strong flexible film, in contrast to the analogous unsupported membrane which, at this low equivalent weight, is extremely fragile and readily reduced to a powder on handling. The wet composite membrane (25-40 micron thick) was also strong and flexible, again in contrast to the unsupported membrane which is fragile and dimensionally unstable, and is therefore of limited use in electrochemical fuel cells.

Example 6

Each of the composite membranes prepared as described above was bonded to two catalyzed carbon fiber paper electrodes at room temperature under 7,500 pounds of pressure. Each membrane electrode assembly was tested in a Ballard Mark IV single cell fuel cell (see U.S. Patent Nos. 4,988,583; 5,108,849; 5,170,124; 5,176,966 and 5,200,278; all 25 incorporated herein by reference in their 30

- 31 -

entirety). The following operating conditions applied to the fuel cell in which the membranes were tested:

Temperature: 70°C

5 Reactant inlet pressure:

24 psi for both air and hydrogen

Reactant stoichiometries:

2.0 air and 1.15 hydrogen.

The membrane electrode assemblies

10 incorporating the composite membranes were tested for 200-1400 hours, depending on availability of testing equipment.

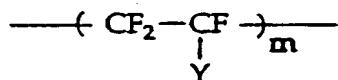
FIGS. 1-5 are polarization plots of voltage as 15 a function of current density for composite membranes A-E, respectively, employed in membrane electrode assemblies in the electrochemical fuel cell. The data is comparable to data reported for unsupported membranes in related U.S. Patent No. 5,422,411.

20 While particular elements, embodiments and applications of the present invention have been shown and described, it will be understood, of course, that the invention is not limited thereto since modifications may be made by those skilled in 25 the art, particularly in light of the foregoing teachings. It is therefore contemplated by the appended claims to cover such modifications as incorporate those features which come within the spirit and scope of the invention.

- 32 -

What is claimed is:

1. A composite membrane comprising a porous substrate impregnated with a polymeric composition comprising α,β,β -trifluorostyrene monomeric units.
2. The composite membrane of claim 1 wherein said polymeric composition further comprises ethylene monomeric units.
3. The composite membrane of claim 1 wherein said polymeric composition further comprises partially fluorinated ethylene monomeric units.
4. The composite membrane of claim 1 wherein said polymeric composition further comprises tetrafluoroethylene monomeric units.
5. The composite membrane of claim 1 wherein said polymeric composition further comprises:



where m is an integer greater than zero; Y is
5 selected from the group consisting of chlorine,
bromine, iodine, $\text{C}_x\text{H}_y\text{F}_z$ (where x is an integer
greater than zero and $y+z = 2x+1$), O-R (where R is
selected from the group consisting of $\text{C}_x\text{H}_y\text{F}_z$ (where x
is an integer greater than zero and $y+z = 2x+1$) and
10 aryls), CF=CF_2 , CN , COOH and CO_2R^1 (where R^1 is

- 33 -

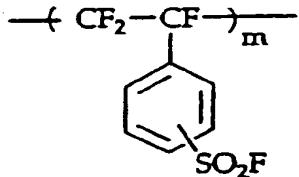
selected from the group consisting of perfluoroalkyls, aryls, and NR²R³ where R² and R³ are selected from the group consisting of hydrogen, alkyls and aryls).

6. The composite membrane of claim 1 wherein said polymeric composition further comprises styrene monomeric units.

7. The composite membrane of claim 1 wherein said polymeric composition further comprises substituted styrene monomeric units.

8. A composite membrane comprising a porous substrate impregnated with a polymeric composition comprising substituted α,β,β-trifluorostyrene monomeric units.

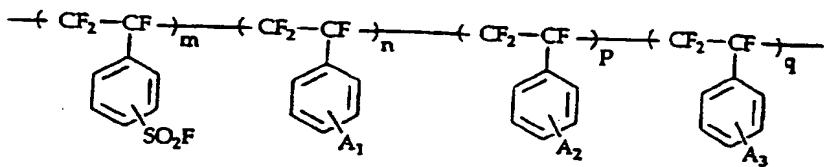
9. The composite membrane of claim 8 wherein said polymeric composition comprises:



where m is an integer greater than zero.

10. The composite membrane of claim 9 wherein said polymeric composition comprises:

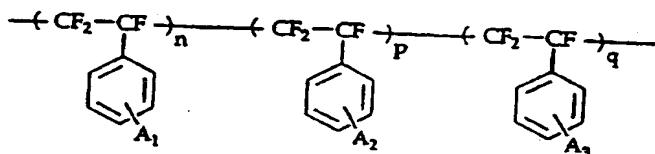
- 34 -



where m is an integer greater than zero, and at least one of n , p and q is an integer greater than zero; A_1 , A_2 and A_3 are selected from the group consisting of hydrogen, halogens, $C_xH_yF_z$ (where x is an integer greater than zero and $y+z = 2x+1$), $CF=CF_2$, CN , NO_2 and OH , $O-R$ (where R is selected from the group consisting of alkyls and perfluoroalkyls and aryls).

11. The composite membrane of claim 10 wherein the group from which A_1 , A_2 and A_3 are selected further consists of SO_3H , PO_2H_2 , PO_3H_2 , $CH_2PO_3H_2$, $COOH$, OSO_3H , OPO_2H_2 , OPO_3H_2 , NR_3^+ (where R is selected from the group consisting of alkyls, perfluoroalkyls and aryls) and $CH_2NR_3^+$ (where R is selected from the group consisting of alkyls, perfluoroalkyls and aryls), and at least one of A_1 , A_2 and A_3 is selected from the group consisting of SO_3H , PO_2H_2 , PO_3H_2 , $CH_2PO_3H_2$, $COOH$, OSO_3H , OPO_2H_2 , OPO_3H_2 , NR_3^+ (where R is selected from the group consisting of alkyls, perfluoroalkyls and aryls) and $CH_2NR_3^+$ (where R is selected from the group consisting of alkyls, perfluoroalkyls and aryls).

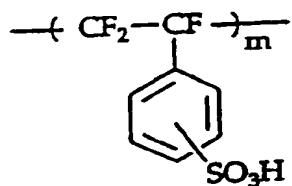
12. The composite membrane of claim 8 wherein said polymeric composition comprises:



- 35 -

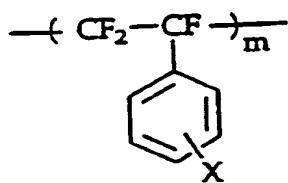
where at least one of n, p and q is an integer
5 greater than zero; A₁, A₂ and A₃ are selected from
the group consisting of CF=CF₂, CN, NO₂ and OH, O-R
(where R is selected from the group consisting of
C_xH_yF_z (where x is an integer greater than three and
y+z = 2x+1), and aryls).

13. The composite membrane of claim 8 wherein
said polymeric composition comprises:



where m is an integer greater than zero.

14. The composite membrane of claim 8 wherein
said polymeric composition comprises:

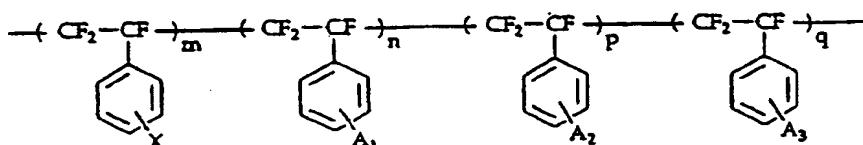


5 where m is an integer greater than zero; X is
selected from the group consisting of PO₂H₂, PO₃H₂,
CH₂PO₂H₂, COOH, OSO₃H, OPO₂H₂, OPO₃H₂, OArSO₃H where Ar
is an aryl, NR₂ (where R is selected from the group

- 36 -

consisting of alkyls, perfluoroalkyls and aryls) and CH₂NR,^{*} (where R is selected from the group consisting of alkyls, perfluoroalkyls and aryls).

15. The composite membrane of claim 8 wherein said polymeric composition comprises:



5 where m is an integer greater than zero, and at least one of n, p and q is an integer greater than zero; X is selected from the group consisting of SO₃H, PO₃H₂, PO₂H₂, CH₂PO₂H₂, COOH, OSO₃H, OPO₂H₂, OPO₃H₂, OArSO₃H where Ar is an aryl, NR,^{*} (where R is selected from the group consisting of alkyls, 10 perfluoroalkyls and aryls) and CH₂NR,^{*} (where R is selected from the group consisting of alkyls, perfluoroalkyls and aryls); A₁, A₂ and A₃ are selected from the group consisting of halogens, C_xH_yF_z (where x is an integer greater than zero and 15 y+z = 2x+1), CF=CF₂, CN, NO₂ and OH, O-R (where R is selected from the group consisting of alkyls and perfluoroalkyls and aryls).

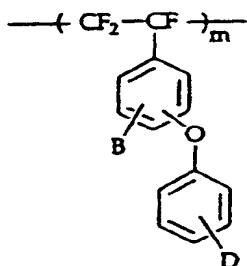
16. The composite membrane of claim 15 wherein the group from which A₁, A₂ and A₃ are selected further consists of hydrogen.

17. The composite membrane of claim 15 wherein the group from which A₁, A₂ and A₃ are

- 37 -

selected further consists of SO₂H, PO₂H₂, PO₂H₂, CH₂PO₂H₂, COOH, OSO₂H, OPO₂H₂, OPO₂H₂, NR,^{*} (where R is selected from the group consisting of alkyls, perfluoroalkyls and aryls) and CH₂NR,^{*} (where R is selected from the group consisting of alkyls, perfluoroalkyls and aryls), and at least one of A₁, A₂ and A₃ is selected from the group consisting of SO₂H, PO₂H₂, PO₂H₂, CH₂PO₂H₂, COOH, OSO₂H, OPO₂H₂, OPO₂H₂, NR,^{*} (where R is selected from the group consisting of alkyls, perfluoroalkyls and aryls) and CH₂NR,^{*} (where R is selected from the group consisting of alkyls, perfluoroalkyls and aryls).

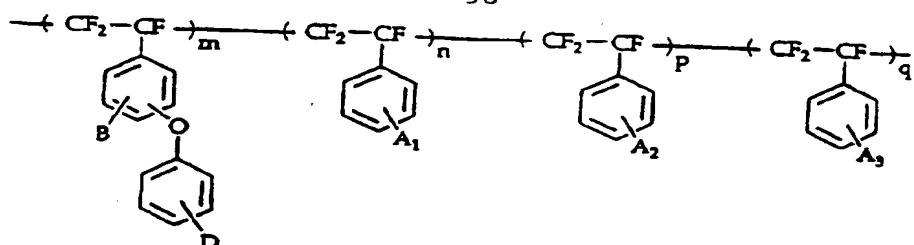
18. The composite membrane of claim 8 wherein said polymeric composition comprises:



5 where m is an integer greater than zero; B and D are selected from the group consisting of hydrogen, SO₂F, SO₂H, PO₂H₂, PO₂H₂, CH₂PO₂H₂, COOH, OSO₂H, OPO₂H₂, OPO₂H₂, NR,^{*} (where R is selected from the group consisting of alkyls, perfluoroalkyls and aryls) and CH₂NR,^{*} (where R is selected from the group consisting of alkyls, perfluoroalkyls and aryls).
10

19. The composite membrane of claim 8 wherein said polymeric composition comprises:

- 38 -



where m is an integer greater than zero, and at least one of n, p and q is an integer greater than zero; B and D are selected from the group consisting of hydrogen, SO₂F, SO₂H, PO₂H₂, PO₃H₂, CH₂PO₂H₂, COOH, OSO₂H, OPO₂H₂, OPO₃H₂, NR,^{*} (where R is selected from the group consisting of alkyls, perfluoroalkyls and aryls) and CH₂NR,^{*} (where R is selected from the group consisting of alkyls, perfluoroalkyls and aryls); A₁, A₂ and A₃ are selected from the group consisting of hydrogen, SO₂F, halogens, C_xH_yF_z (where x is an integer greater than zero and y+z = 2x+1), CF=CF₂, CN, NO₂ and OH, O-R (where R is selected from the group consisting of alkyls and perfluoroalkyls and aryls).

20. The composite membrane of claim 19 wherein the group from which A₁, A₂ and A₃ are selected further consists of SO₂H, PO₂H₂, PO₃H₂, CH₂PO₂H₂, COOH, OSO₂H, OPO₂H₂, OPO₃H₂, NR,^{*} (where R is selected from the group consisting of alkyls, perfluoroalkyls and aryls) and CH₂NR,^{*} (where R is selected from the group consisting of alkyls, perfluoroalkyls and aryls), and at least one of A₁, A₂ and A₃ is selected from the group consisting of SO₂H, PO₂H₂, PO₃H₂, CH₂PO₂H₂, COOH, OSO₂H, OPO₂H₂, OPO₃H₂, NR,^{*} (where R is selected from the group consisting of alkyls, perfluoroalkyls and aryls) and CH₂NR,^{*} (where R is selected from the group consisting of alkyls, perfluoroalkyls and aryls).

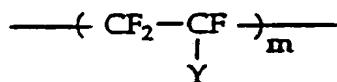
- 39 -

21. The composite membrane of claim 8 wherein said polymeric composition further comprises ethylene monomeric units.

22. The composite membrane of claim 8 wherein said polymeric composition further comprises partially fluorinated ethylene monomeric units.

23. The composite membrane of claim 8 wherein said polymeric composition further comprises tetrafluoroethylene monomeric units.

24. The composite membrane of claim 8 wherein said polymeric composition further comprises:



where m is an integer greater than zero; Y is
5 selected from the group consisting of chlorine,
bromine, iodine, $\text{C}_x\text{H}_y\text{F}_z$ (where x is an integer
greater than zero and $y+z = 2x+1$), O-R (where R is
selected from the group consisting of $\text{C}_x\text{H}_y\text{F}_z$ (where x
is an integer greater than zero and $y+z = 2x+1$) and
10 aryls), $\text{CF}=\text{CF}_2$, CN, COOH and $\text{CO}_2\text{R}'$ (where R' is
selected from the group consisting of alkyls,
perfluoroalkyls, aryls, and $\text{NR}^2\text{R}'^3$ where R^2 and R'^3 are
selected from the group consisting of hydrogen,
alkyls and aryls).

25. The composite membrane of claim 8 wherein

- 40 -

said polymeric composition further comprises styrene monomeric units.

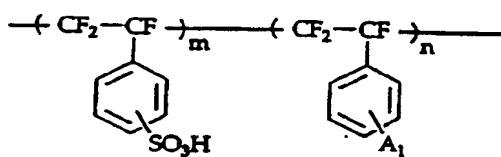
26. The composite membrane of claim 8 wherein said polymeric composition further comprises substituted styrene monomeric units.

27. The composite membrane of claims 1-26 wherein said porous substrate comprises a polyolefin.

28. The composite membrane of claim 27 wherein said polyolefin is selected from the group consisting of polyethylene and polypropylene.

29. The composite membrane of claims 1-26 wherein said porous substrate comprises polytetrafluoroethylene.

30. A composite membrane comprising a porous substrate impregnated with a polymeric composition comprising:



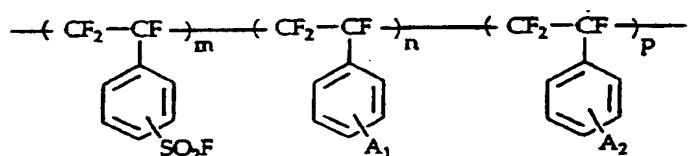
5 where m and n are integers greater than zero and A₁ is selected from the group consisting of fluorine, CF, and para-phenoxy.

- 41 -

31. The composite membrane of claim 30 wherein the group from which A₁ is selected further consists of hydrogen.

32. The composite membrane of claim 31 wherein said porous substrate comprises polytetrafluoroethylene.

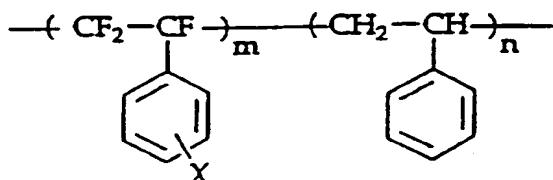
33. A composite membrane comprising a porous substrate impregnated with a polymeric composition comprising:



where m, n, and p are integers greater than zero and A₁ and A₂ are selected from the group consisting of hydrogen, fluorine, CF₃, and para-phenoxy.

34. The composite membrane of claim 33 wherein said porous substrate comprises polytetrafluoroethylene.

35. A composite membrane comprising a porous substrate impregnated with a polymeric composition comprising:

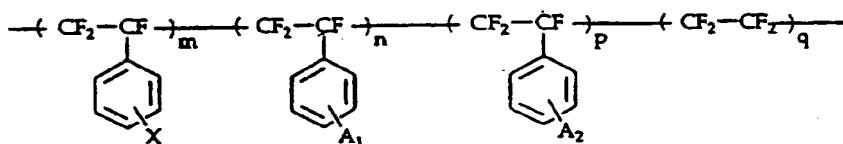


- 42 -

where m and n are integers greater than zero and X is selected from the group consisting of para-SO₂F, meta-SO₂H and para-SO₂H.

36. The composite membrane of claim 35 wherein said porous substrate comprises polytetrafluoroethylene.

37. A composite membrane comprising a porous substrate impregnated with a polymeric composition comprising:



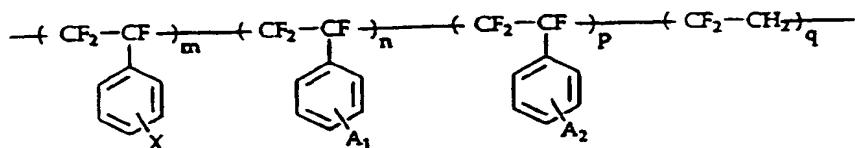
5 where m and q are integers greater than zero, n and p are zero or an integer greater than zero; X is selected from the group consisting of para-SO₂F, meta-SO₂H and para-SO₂H; and A₁ and A₂ are selected from the group consisting of hydrogen, fluorine, CF₃, and para-phenoxy.
10

38. The composite membrane of claim 37 wherein said porous substrate comprises polytetrafluoroethylene.

39. The composite membrane of claim 37 wherein n is an integer greater than zero.

- 43 -

40. A composite membrane comprising a porous substrate impregnated with a polymeric composition comprising:



5 where m and q are integers greater than zero, n and
 p are zero or an integer greater than zero; X is
 selected from the group consisting of para- SO_2F ,
 meta- SO_2H and para- SO_2H ; and A_1 and A_2 are selected
 from the group consisting of hydrogen, fluorine,
10 CF_3 , and para-phenoxy.

41. The composite membrane of claim 40 wherein
said porous substrate comprises
polytetrafluoroethylene.

42. The composite membrane of claim 40
wherein n is an integer greater than zero.

43. A composite membrane comprising a porous substrate impregnated with a polymeric composition consisting essentially of α,β,β -trifluorostyrene monomeric units.

44. A composite membrane comprising a porous substrate impregnated with a polymeric composition consisting essentially of α,β,β -trifluorostyrene and ethylene monomeric units.

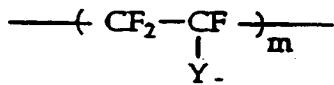
- 44 -

45. A composite membrane comprising a porous substrate impregnated with a polymeric composition consisting essentially of α,β,β -trifluorostyrene and partially fluorinated ethylene monomeric units.

46. A composite membrane comprising a porous substrate impregnated with a polymeric composition consisting essentially of α,β,β -trifluorostyrene and tetrafluoroethylene monomeric units.

47. A composite membrane comprising a porous substrate impregnated with a polymeric composition consisting essentially of α,β,β -trifluorostyrene monomeric units and:

5



where m is an integer greater than zero; Y is selected from the group consisting of chlorine, bromine, iodine, $\text{C}_x\text{H}_y\text{F}_z$ (where x is an integer greater than zero and $y+z = 2x+1$), O-R (where R is selected from the group consisting of $\text{C}_x\text{H}_y\text{F}_z$ (where x is an integer greater than zero and $y+z = 2x+1$) and aryls), $\text{CF}=\text{CF}_2$, CN, COOH and $\text{CO}_2\text{R}'$ (where R' is selected from the group consisting of perfluoroalkyls, aryls, and $\text{NR}^2\text{R}'$ where R^2 and R' are selected from the group consisting of hydrogen, alkyls and aryls).

48. A composite membrane comprising a porous

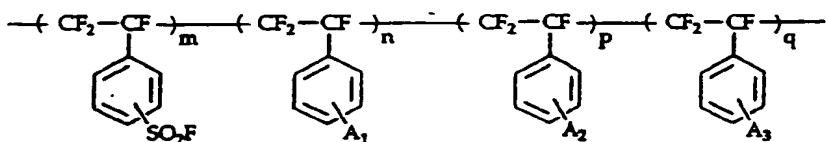
- 45 -

substrate impregnated with a polymeric composition consisting essentially of α,β,β -trifluorostyrene and styrene monomeric units.

49. A composite membrane comprising a porous substrate impregnated with a polymeric composition consisting essentially of α,β,β -trifluorostyrene and substituted styrene monomeric units.

50. A composite membrane comprising a porous substrate impregnated with a polymeric composition consisting essentially of substituted α,β,β -trifluorostyrene monomeric units.

51. A composite membrane comprising a porous substrate impregnated with a polymeric composition consisting essentially of:



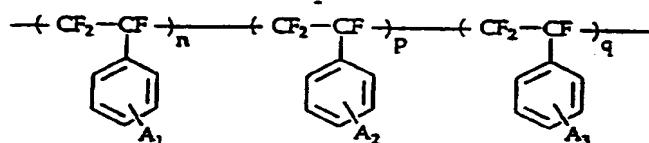
5 where m is an integer greater than zero, and at least one of n , p and q is an integer greater than zero; A_1 , A_2 and A_3 are selected from the group consisting of hydrogen, halogens, $\text{C}_x\text{H}_y\text{F}_z$ (where x is an integer greater than zero and $y+z = 2x+1$),
10 $\text{CF}=\text{CF}_2$, CN , NO_2 , and OH , $\text{O}-\text{R}$ (where R is selected from the group consisting of alkyls and perfluoroalkyls and aryls).

52. The composite membrane of claim 51

- 46 -

wherein the group from which A₁, A₂ and A₃ are selected further consists of SO₃H, PO₂H₂, PO₃H₂, CH₂PO₂H₂, COOH, OSO₃H, OPO₂H₂, OPO₃H₂, NR,^{*} (where R is selected from the group consisting of alkyls, perfluoroalkyls and aryls) and CH₂NR,^{*} (where R is selected from the group consisting of alkyls, perfluoroalkyls and aryls), and at least one of A₁, A₂ and A₃ is selected from the group consisting of 5 SO₃H, PO₂H₂, PO₃H₂, CH₂PO₂H₂, COOH, OSO₃H, OPO₂H₂, OPO₃H₂, NR,^{*} (where R is selected from the group consisting of alkyls, perfluoroalkyls and aryls) and CH₂NR,^{*} (where R is selected from the group 10 consisting of alkyls, perfluoroalkyls and aryls).

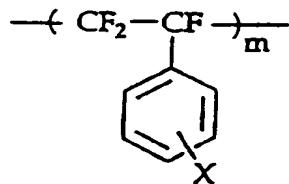
53. The composite membrane of claim 50 wherein said polymeric composition consists essentially of:



5 where at least one of n, p and q is an integer greater than zero; A₁, A₂ and A₃ are selected from the group consisting of CF=CF₂, CN, NO₂ and OH, O-R 10 (where R is selected from the group consisting of C_xH_yF, (where x is an integer greater than three and y+z = 2x+1), and aryls).

54. The composite membrane of claim 50 wherein said polymeric composition consists essentially of:

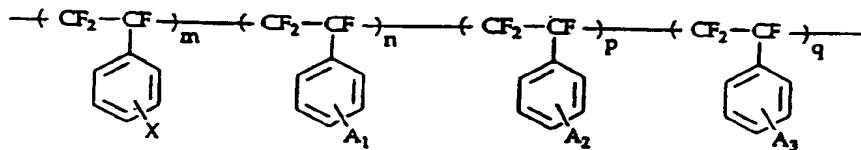
- 47 -



5 where m is an integer greater than zero; X is selected from the group consisting of PO_2H_2 , PO_2H_2 , $\text{CH}_2\text{PO}_2\text{H}_2$, COOH , OSO_2H , OPO_2H_2 , OPO_2H_2 , OArSO_2H where Ar is an aryl, NR_3^+ (where R is selected from the group consisting of alkyls, perfluoroalkyls and aryls) and CH_2NR_3^+ (where R is selected from the group consisting of alkyls, perfluoroalkyls and aryls).

10

55. A composite membrane comprising a porous substrate impregnated with a polymeric composition consisting essentially of:



5 where m is an integer greater than zero, and at least one of n , p and q is an integer greater than zero; X is selected from the group consisting of SO_3H , PO_2H_2 , PO_2H_2 , $\text{CH}_2\text{PO}_2\text{H}_2$, COOH , OSO_2H , OPO_2H_2 , OPO_2H_2 , OArSO_2H where Ar is an aryl, NR_3^+ (where R is selected from the group consisting of alkyls, perfluoroalkyls and aryls) and CH_2NR_3^+ (where R is selected from the group consisting of alkyls, perfluoroalkyls and aryls); A_1 , A_2 and A_3 are

10

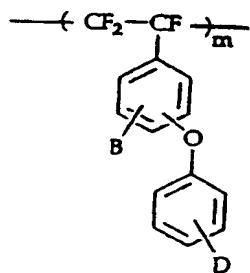
- 48 -

selected from the group consisting of halogens,
15 $C_xH_yF_z$ (where x is an integer greater than zero and
 $y+z = 2x+1$), $CF=CF_2$, CN, NO_2 and OH, O-R (where R is
selected from the group consisting of alkyls and
perfluoroalkyls and aryls).

56. The composite membrane of claim 55
wherein the group from which A_1 , A_2 and A_3 are
selected further consists of hydrogen.

57. The composite membrane of claim 55
wherein the group from which A_1 , A_2 and A_3 are
selected further consists of SO_3H , PO_2H_2 , PO_3H_2 ,
 $CH_2PO_2H_2$, COOH, OSO_3H , OPO_2H_2 , OPO_3H_2 , NR,^{*} (where R is
5 selected from the group consisting of alkyls,
perfluoroalkyls and aryls) and CH_2NR ,^{*} (where R is
selected from the group consisting of alkyls,
perfluoroalkyls and aryls), and at least one of A_1 ,
 A_2 and A_3 is selected from the group consisting of
10 SO_3H , PO_2H_2 , PO_3H_2 , $CH_2PO_2H_2$, COOH, OSO_3H , OPO_2H_2 ,
 OPO_3H_2 , NR,^{*} (where R is selected from the group
consisting of alkyls, perfluoroalkyls and aryls)
and CH_2NR ,^{*} (where R is selected from the group
consisting of alkyls, perfluoroalkyls and aryls).

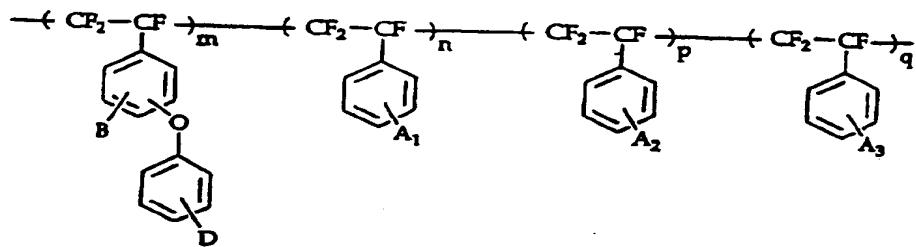
58. The composite membrane of claim 50
wherein said polymeric composition consists
essentially of:



- 49 -

5 where m is an integer greater than zero; B and D
are selected from the group consisting of hydrogen,
SO₂F, SO₂H, PO₂H₂, PO₂H₂, CH₂PO₂H₂, COOH, OSO₂H, OPO₂H₂,
OPO₂H₂, NR,^{*} (where R is selected from the group
consisting of alkyls, perfluoroalkyls and aryls)
10 and CH₂NR,^{*} (where R is selected from the group
consisting of alkyls, perfluoroalkyls and aryls).

59. A composite membrane comprising a porous
substrate impregnated with a polymeric composition
consisting essentially of:



5 where m is an integer greater than zero and at
least one of n, p and q is an integer greater than
zero; B and D are selected from the group
consisting of hydrogen, SO₂F, SO₂H, PO₂H₂, PO₂H₂,
CH₂PO₂H₂, COOH, OSO₂H, OPO₂H₂, OPO₂H₂, NR,^{*} (where R is
10 selected from the group consisting of alkyls,
perfluoroalkyls and aryls) and CH₂NR,^{*} (where R is
selected from the group consisting of alkyls,
perfluoroalkyls and aryls); A₁, A₂ and A₃ are
selected from the group consisting of hydrogen,
15 SO₂F, halogens, C_xH_yF_z (where x is an integer greater
than zero and y+z = 2x+1), CF=CF₂, CN, NO₂ and OH,
O-R (where R is selected from the group consisting
of alkyls and perfluoroalkyls and aryls).

- 50 -

60. The composite membrane of claim 59 wherein the group from which A₁, A₂ and A₃ are selected further consists of SO₃H, PO₂H₂, PO₃H₂, CH₂PO₂H₂, COOH, OSO₃H, OPO₂H₂, OPO₃H₂, NR,^{*} (where R is selected from the group consisting of alkyls, perfluoroalkyls and aryls) and CH₂NR,^{*} (where R is selected from the group consisting of alkyls, perfluoroalkyls and aryls), and at least one of A₁, A₂ and A₃ is selected from the group consisting of SO₃H, PO₂H₂, PO₃H₂, CH₂PO₂H₂, COOH, OSO₃H, OPO₂H₂, OPO₃H₂, NR,^{*} (where R is selected from the group consisting of alkyls, perfluoroalkyls and aryls) and CH₂NR,^{*} (where R is selected from the group consisting of alkyls, perfluoroalkyls and aryls).

61. A composite membrane comprising a porous substrate impregnated with a polymeric composition consisting essentially of substituted α,β,β-trifluorostyrene monomeric units and ethylene monomeric units.

62. A composite membrane comprising a porous substrate impregnated with a polymeric composition consisting essentially of substituted α,β,β-trifluorostyrene monomeric units and partially fluorinated ethylene monomeric units.

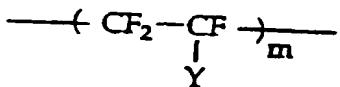
63. A composite membrane comprising a porous substrate impregnated with a polymeric composition consisting essentially of substituted α,β,β-trifluorostyrene monomeric units and tetrafluoroethylene monomeric units.

64. A composite membrane comprising a porous

- 51 -

substrate impregnated with a polymeric composition consisting essentially of substituted α,β,β -trifluorostyrene monomeric units and:

5



where m is an integer greater than zero; Y is selected from the group consisting of chlorine, bromine, iodine, $C_xH_yF_z$ (where x is an integer greater than zero and $y+z = 2x+1$), O-R (where R is selected from the group consisting of $C_xH_yF_z$ (where x is an integer greater than zero and $y+z = 2x+1$) and aryls), $CF=CF_2$, CN, COOH and CO_2R^1 (where R^1 is selected from the group consisting of alkyls, perfluoroalkyls, aryls, and NR^2R^3 where R^2 and R^3 are selected from the group consisting of hydrogen, alkyls and aryls).

10

65. A composite membrane comprising a porous substrate impregnated with a polymeric composition consisting essentially of substituted α,β,β -trifluorostyrene monomeric units and styrene monomeric units.

5

66. A composite membrane comprising a porous substrate impregnated with a polymeric composition consisting essentially of substituted α,β,β -trifluorostyrene monomeric units and substituted styrene monomeric units.

5

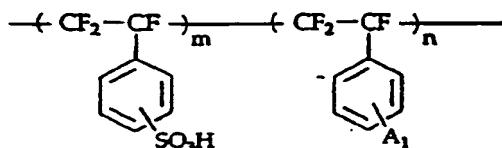
- 52 -

67. The composite membrane of claims 43-66 wherein said porous substrate consists essentially of a polyolefin.

68. The composite membrane of claim 67 wherein said polyolefin is selected from the group consisting of polyethylene and polypropylene.

69. The composite membrane of claims 43-66 wherein said porous substrate consists essentially of polytetrafluoroethylene.

70. A composite membrane comprising a porous substrate impregnated with a polymeric composition consisting essentially of:



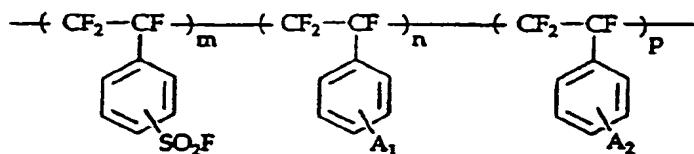
5 where m and n are integers greater than zero and A_1 is selected from the group consisting of fluorine, CF_3 , and para-phenoxy.

71. The composite membrane of claim 70 wherein the group from which A_1 is selected further consists of hydrogen.

72. The composite membrane of claim 71 wherein said porous substrate consists essentially of polytetrafluoroethylene.

- 53 -

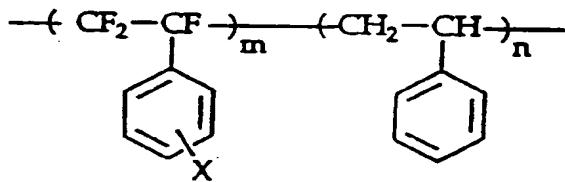
73. A composite membrane comprising a porous substrate impregnated with a polymeric composition consisting essentially of:



5 where m, n, and p are integers greater than zero and A₁ and A₂ are selected from the group consisting of hydrogen, fluorine, CF₃, and para-phenoxy.

10 74. The composite membrane of claim 73 wherein said porous substrate consisting essentially of polytetrafluoroethylene.

75. A composite membrane comprising a porous substrate impregnated with a polymeric composition consisting essentially of:



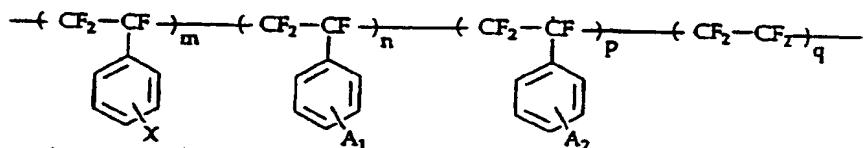
5 where m and n are integers greater than zero and X is selected from the group consisting of para-SO₂F, meta-SO₂H and para-SO₂H.

76. The composite membrane of claim 75 wherein said porous substrate consists essentially

- 54 -

of polytetrafluoroethylene.

77. A composite membrane comprising a porous substrate impregnated with a polymeric composition consisting essentially of:

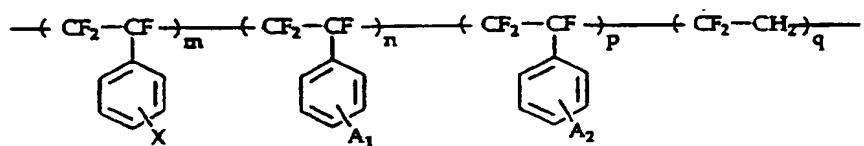


where m and q are integers greater than zero, n and p are zero or an integer greater than zero; X is selected from the group consisting of para-SO₂F, meta-SO₂H and para-SO₂H; and A₁ and A₂ are selected from the group consisting of hydrogen, fluorine, CF₃, and para-phenoxy.

78. The composite membrane of claim 77 wherein said porous substrate consists essentially of polytetrafluoroethylene.

79. The composite membrane of claim 77 wherein n is an integer greater than zero.

80. A composite membrane comprising a porous substrate impregnated with a polymeric composition consisting essentially of:



5 where m and q are integers greater than zero, n and
p are zero or an integer greater than zero; X is
selected from the group consisting of para-SO₂F,
meta-SO₂H and para-SO₂H; and A₁ and A₂ are selected
from the group consisting of hydrogen, fluorine,
10 CF₃, and para-phenoxy.

81. The composite membrane of claim 80 wherein
said porous substrate consists essentially of
polytetrafluoroethylene.

82. The composite membrane of claim 80 where
n is an integer greater than zero.

1/3

FIG. 1

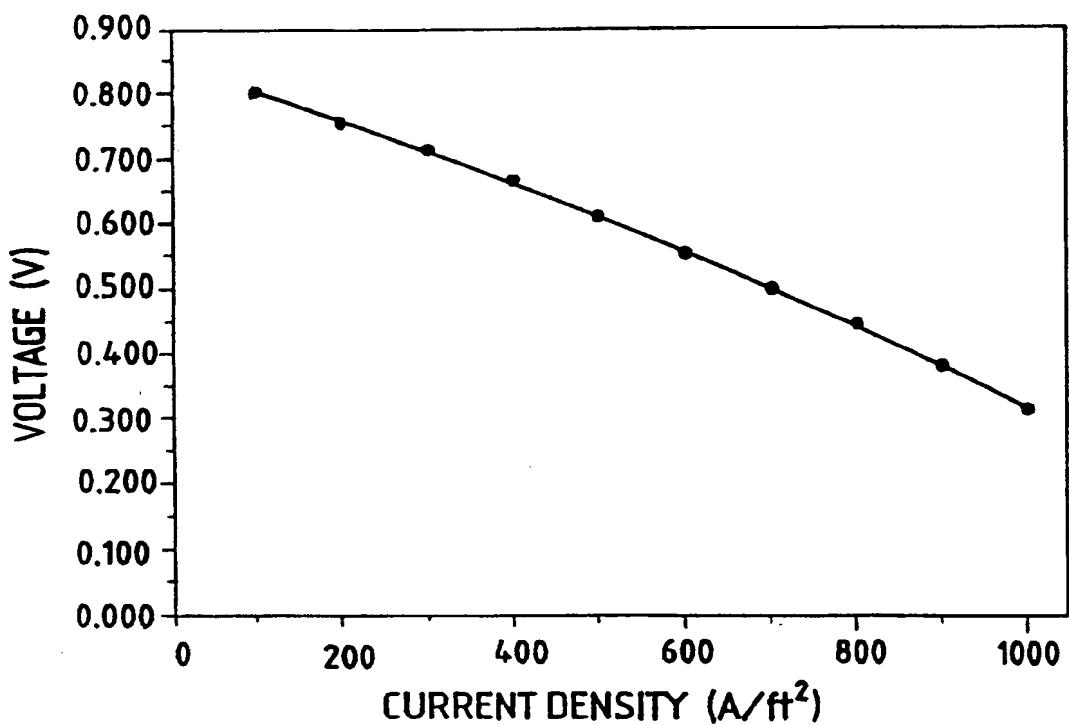
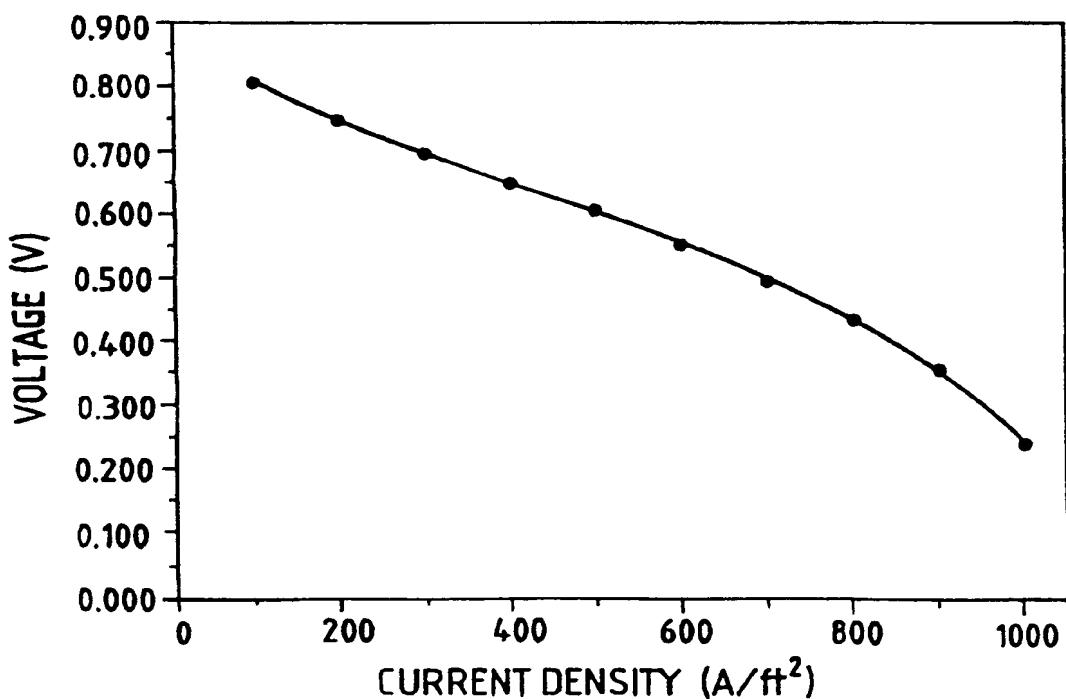


FIG. 2



2/3

FIG. 3

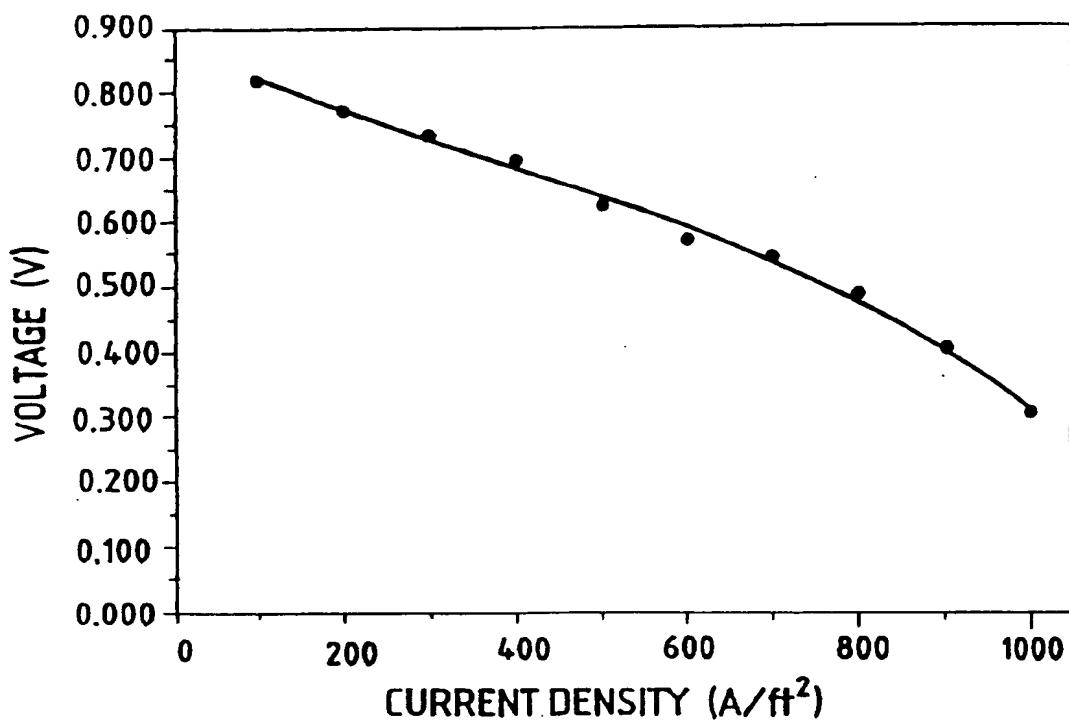
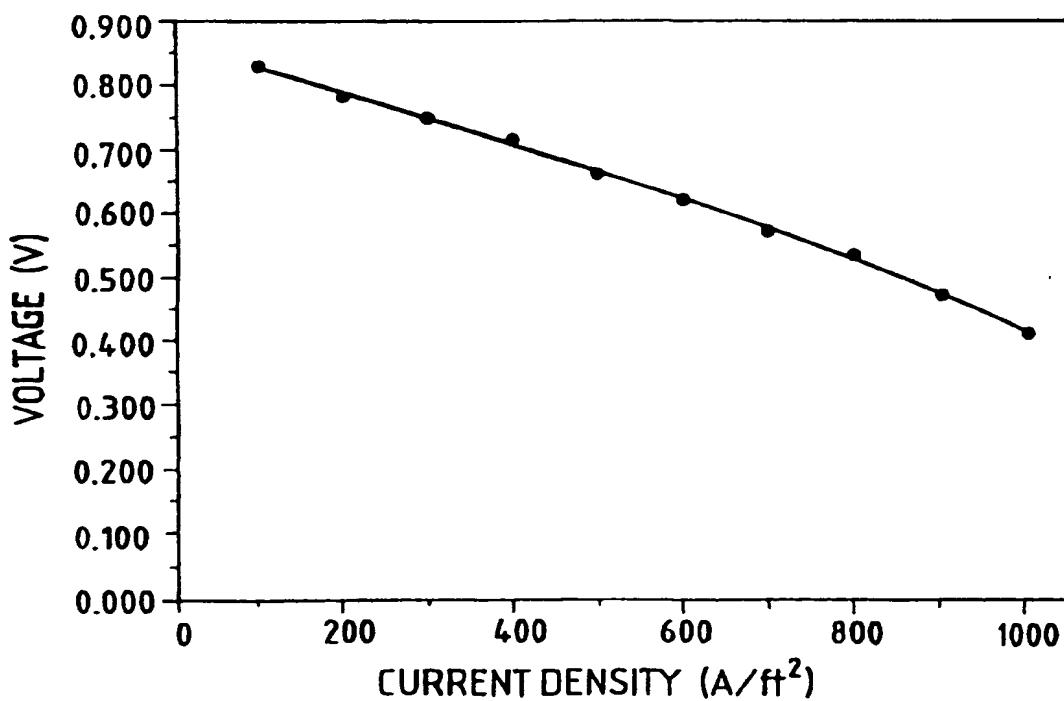
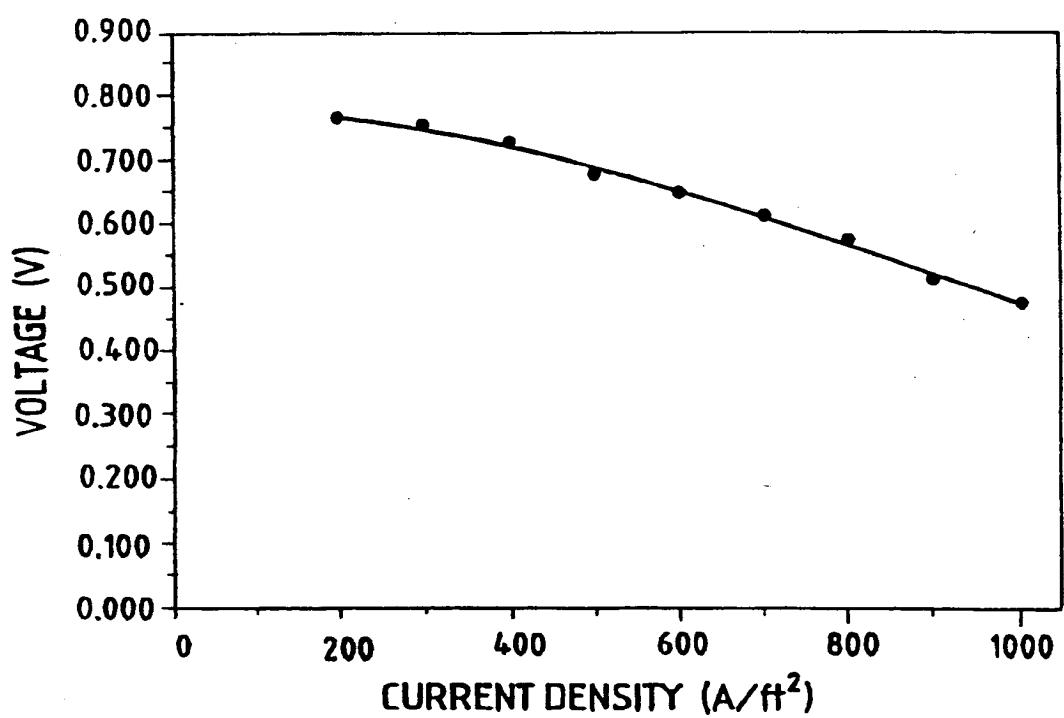


FIG. 4



3/3

FIG. 5

INTERNATIONAL SEARCH REPORT

Int'l Application No
PCT/97/00003

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 C08J5/22

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 C08J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
P,A	WO 96 40798 A (BALLARD POWER SYSTEMS ;STONE CHARLES (CA); STECK ALFRED E (CA)) 19 December 1996 cited in the application ---	
P,A	WO 96 39379 A (BALLARD POWER SYSTEMS ;STONE CHARLES (CA); STECK ALFRED E (CA); L0) 12 December 1996 cited in the application ---	
A	WO 95 08581 A (BALLARD POWER SYSTEMS) 30 March 1995 & US 5 422 411 A cited in the application ---	
P,A	WO 96 28242 A (GORE & ASS) 19 September 1996 --- -/-	

Further documents are listed in the continuation of box C.

Patent family members are listed in annex.

* Special categories of cited documents :

- 'A' document defining the general state of the art which is not considered to be of particular relevance
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- 'L' document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- 'O' document referring to an oral disclosure, use, exhibition or other means
- 'P' document published prior to the international filing date but later than the priority date claimed

- 'T' later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- 'X' document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
- 'Y' document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
- '&' document member of the same patent family

Date of the actual completion of the international search

6 May 1997

Date of mailing of the international search report

20.05.97

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INTERNATIONAL SEARCH REPORT

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